

Frequency of Precipitation across the Northern U.S. Corn Belt

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ABSTRACT

Knowledge of the frequency of precipitation events can aid in managing water resources, but little is known concerning the regional variability in the frequency of daily precipitation events in the northern U.S. Corn Belt. The frequency distribution of daily precipitation events, varying from 0.25 to 102 mm, was examined at 15 climate stations in Minnesota, South Dakota, Iowa, and Wisconsin. Data were available from 1898 to 1997. Annual precipitation and frequency of precipitation events increased from the NW to the SE across the northern Corn Belt. The frequency of daily precipitation events (of at least 0.25 mm) at all stations remained fairly persistent (at about 20%) during winter then increased during spring before attaining a maximum near 35% in late May or June. The frequency of events then declined to about 25% by late August before approaching a secondary maximum of about 30% in September. The frequency distribution of daily precipitation events was skewed, with more frequent events occurring earlier in the year at all but the two most eastern stations. The transition from winter to spring precipitation patterns was delayed about 15 days at western as compared with eastern stations. Precipitation events were twice as frequent in the spring than in the autumn at western stations and 30% more frequent in spring than in autumn at eastern stations. This study suggests that daily precipitation events in the northern Corn Belt occur with greater frequency in the SE than in the NW and in the spring than in the autumn. This regional and seasonal variability in precipitation must be considered when designing hydrologic systems and managing agricultural and natural resources.

1. Introduction

The distribution and frequency of daily precipitation events have important implications for agriculture as well as for management of natural resources. Crop diversification and production, for example, depend not only on total precipitation, but also on the distribution of precipitation during the growing season. In addition, rural and urban water supplies can be better managed by knowing the intraannual frequency of daily precipitation events. Furthermore, human and natural resources can be managed to abate flooding of rivers during critical seasons of the year. In the Great Plains of North America, flooding is of concern in the spring because of snowmelt runoff or precipitation events that occur while soils are frozen (Steppuhn 1981).

Knowledge of the frequency of daily precipitation events in the northern U.S. Corn Belt is vital to managing agricultural chemicals on landscapes. The effec-

tiveness of chemicals in controlling soil and crop pests depends in part on precipitation intensity after pesticide application. Rain occurring soon after application of soil-applied pesticides may be beneficial for incorporating pesticides into the soil, but may also be detrimental to preserving water quality of surface and groundwater systems due to runoff or leaching. Recent interest in applying agricultural chemicals to northern U.S. soils in the autumn of the year has prompted U.S. chemical companies to license products for autumn application. Advantages of applying chemicals in autumn include minimizing field operations in the spring (Holmberg 1998) as well as minimizing the loss of chemicals via runoff. Runoff is less likely to occur in autumn because of less frequent rains in autumn than in spring (Shaw et al. 1960).

Baker and Kuehnast (1973) found that, over a 5-yr period in central Minnesota, daily rainfall (0.25 mm or more) events were 20% more frequent in May than in September. Daily precipitation events of at least 10 mm, however, were more frequent in September than in May. Thus, precipitation occurs on more days in May, but heavier precipitation events occur more often in September than in May in Minnesota. Baker and Kuehnast

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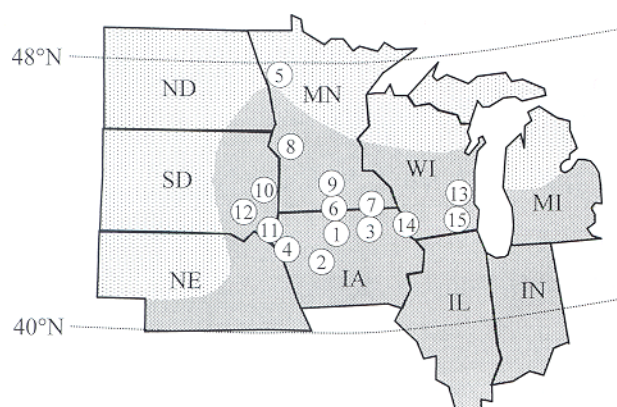


FIG. 1. Location of climate stations (numbered according to Table 1) used in the analysis of frequency of daily precipitation in the U.S. Corn Belt (dark shaded area).

did not assess precipitation frequency before May or after September. In an earlier study, Shaw et al. (1960) found the frequency of weekly precipitation amounts throughout the year to vary across the north-central United States. Based upon 25–61 yr of data, weekly precipitation frequencies at western locations were normally distributed with a maximal frequency occurring near early June, whereas frequencies at eastern locations varied little throughout the year. They also found a greater probability of receiving 2.5 mm or more of precipitation in a week at eastern than at western locations. In addition, precipitation events were more frequent in spring (April–May) than in the autumn (October–November). Huff and Angel (1992) found that extreme precipitation events (the top-ranked one-day event during the year) were most frequent in summer and that these events occurred more often in autumn (Septem-

ber–November) than in spring (March–May) in the midwestern United States.

An understanding of the frequency distribution in daily precipitation across the northern U.S. Corn Belt is important for managing human and natural resources. Our aim was to assess the frequency of daily precipitation events throughout the year for identifying days with frequent or less frequent precipitation at locations across the northern Corn Belt. This information can then aid in scheduling field operations and using water resources in farm production systems.

2. Materials and methods

Spatial and temporal patterns in the frequency distribution of daily precipitation events were analyzed for climate stations in the northern U.S. Corn Belt. The northern Corn Belt was defined, for the purpose of this study, as the area that lies between 42° and 48°N latitude and 88° and 96°W longitude. The area to the north of about 42°N latitude delineates a region characterized by a cold, humid, or subhumid climate (Thorntwaite 1931; Gates 1972). In addition, this area lies in a region of North America with cold winters, seasonally frozen soils (Lunardini 1981), and a mean annual temperature below 10°C (Wilson 1969).

Climate stations within the northern U.S. Corn Belt having a 100-yr-record of precipitation were considered in this analysis. Fifteen stations (Fig. 1) were selected for analysis based upon completeness of the precipitation record as well as their spatial distribution within the northern Corn Belt. A brief history of these stations is given in Table 1. All stations were relocated during the 100-yr period. Relocation of a station is suspected to have little effect on the results of this study, because precipitation is relatively uniform over a 300 km² area

TABLE 1. Climate stations used in the analysis of frequency of precipitation across the northern U.S. Corn Belt.

Name	Reference No. ^a	Station location ^b			Year established	Station moves ^c		Missing data (days)
		State	Lat	Long		No.	Distance (km)	
Algona 3W	1	IA	43°04'N	94°18'W	1861	7	3.0	622
Carroll	2	IA	42°04'N	94°51'W	1889	8	3.5	340
Charles City	3	IA	43°03'N	92°40'W	1875	4	1.5	92
Sioux City	4	IA	42°24'N	96°23'W	1857	4	1.5	53
Crookston	5	MN	47°48'N	96°37'W	1885	3	1.5	175
Fairmont	6	MN	43°38'N	94°28'W	1887	2	1.0	136
Grand Meadow	7	MN	43°42'N	92°34'W	1887	3	1.0	59
Morris	8	MN	43°35'N	95°53'W	1885	1	1.5	280
New Ulm	9	MN	44°18'N	94°27'W	1864	2	2.5	47
Brookings 2NE	10	SD	44°19'N	96°46'W	1888	3	1.5	97
Centerville 6SE	11	SD	43°03'N	96°54'W	1897	8	10.0	720
Mitchell 2N	12	SD	43°44'N	98°01'W	1891	11	5.0	418
Fond du Lac	13	WI	43°48'N	88°27'W	1886	4	2.0	425
Prairie du Chien	14	WI	43°02'N	91°09'W	1822	5	1.5	343
Watertown	15	WI	43°11'N	88°44'W	1891	3	1.5	399

^a Number corresponds to station location in Fig. 1.

^b Current location.

^c Distance is radius of area within which station has moved since 1898 based upon available information from station histories.

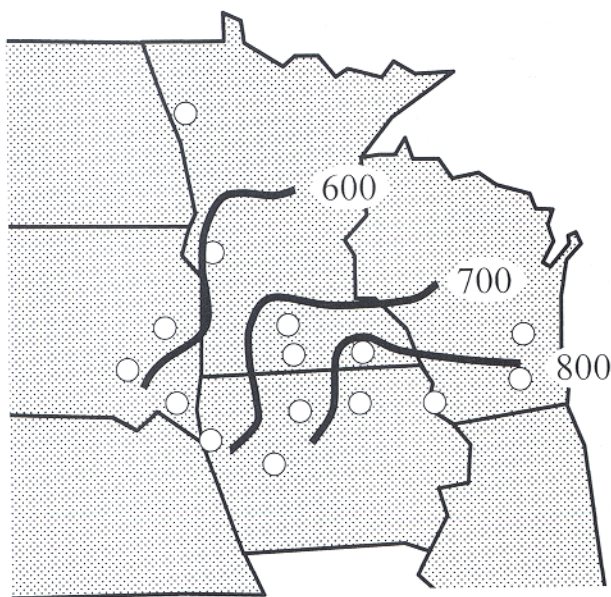


FIG. 2. Isopleths of annual precipitation (mm) across the northern Corn Belt from 1898 to 1997.

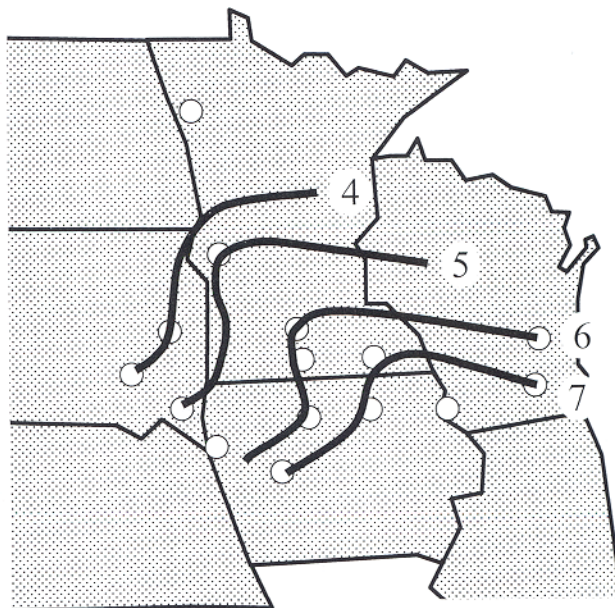


FIG. 3. Isopleths of the median number of daily precipitation events that exceed 10 mm based upon 100 yr of data for climate stations in the northern Corn Belt.

in the northern Corn Belt (Hudson et al. 1952; Baker and Kuehnast 1973). The uniformity of precipitation falling within an area, however, diminishes with storm intensity (Huff and Angel 1992).

Daily precipitation data from 1898 to 1997 were obtained from the TD-3200 digital database maintained by the National Climatic Data Center (Kunkel et al. 1998). Data retrieval options allowed identification of missing precipitation observations (days on which no measurement was recorded by the station observer); these observations were not included in the analysis. No adjustments were made to the precipitation amount on the day following a missing observation. Precipitation events occurring on 29 February (leap year) were omitted from the analysis. Daily precipitation was recorded with an accuracy of 0.25 mm. The frequency of precipitation events for each day of the year was assessed over the 100-yr record. This frequency was determined for daily precipitation events of at least 0.25, 2.5, 5, 10, 15, 20, 25, 30, 41, 51, 64, 76, 89, and 102 mm. Temporal trends in the frequency distribution of precipitation events were clarified by smoothing the data using a 15-day running average and by averaging the frequency by climatological week. Trends in the time series of the frequency of precipitation events were also examined for persistence by assessing lag-one autocorrelation coefficients. In addition, skewness and kurtosis were used to evaluate the normalcy of the frequency distribution.

3. Results and discussion

Annual precipitation increased from northwest to southeast across the northern Corn Belt (Fig. 2). Precipitation at the 15 climate stations considered in this

study varied from 516 mm yr⁻¹ at Crookston, Minnesota, to 823 mm yr⁻¹ at Charles City, Iowa, and Watertown, Wisconsin. Northwestern stations were drier, in part because of a lower frequency of precipitation events than at southeastern stations. This is exemplified by the spatial characteristic in the median frequency of daily precipitation greater than 10 mm across the northern Corn Belt (Fig. 3). Similar spatial trends were found for lesser and greater amounts of precipitation; however, precipitation greater than 10 mm day⁻¹ is often needed to exceed daily evaporative losses during the summer in the northern Corn Belt (Baker et al. 1979). The median frequency of daily precipitation varied from 3% at Crookston, Minnesota, to 7% at Carroll and Charles City, Iowa; Grand Meadow, Minnesota; and Prairie du Chien and Watertown, Wisconsin. In addition, northwest stations were drier as a result of precipitation events being less intense than at southeast stations. For example, averaged across all days with precipitation, events ranged from 1.7 mm day⁻¹ at Crookston, Minnesota, and 2.0 mm day⁻¹ at Morris, Minnesota, and Sioux City, Iowa, to 2.5 mm day⁻¹ at Carroll and Charles City, Iowa, and Prairie du Chien, Wisconsin.

The frequency of daily precipitation exceeding 0.25 and 10 mm during the year, based upon 100 yr of data, for the 15 climate stations is illustrated in Fig. 4. The frequency of daily precipitation events exceeding 0.25 mm during winter varied among locations with the lowest frequencies occurring at the western stations (South Dakota) and the highest frequencies occurring at the eastern stations (Wisconsin). Indeed, the average frequency in daily precipitation for December–February ranged from 12.9% at Brookings and 13.4% at Mitchell

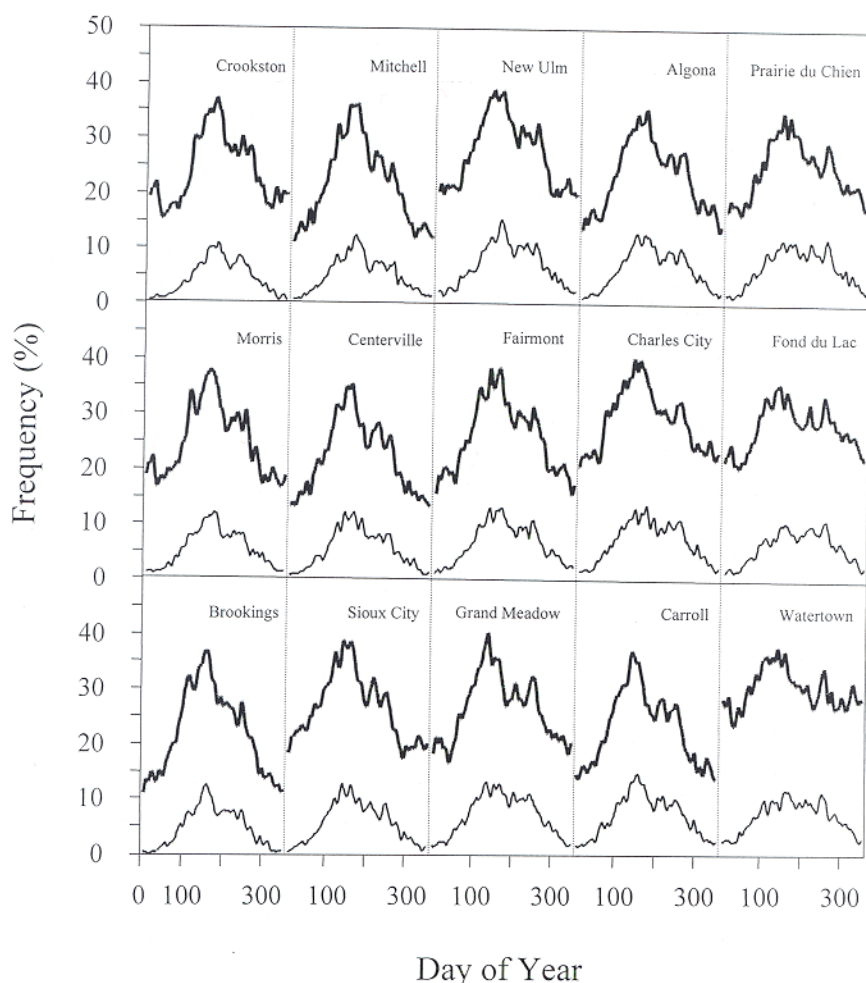


FIG. 4. Frequency distribution (smoothed using a 15-day weighted running average) of daily precipitation that exceeds 0.25 mm (bold, upper line) and 10 mm at 15 climate stations in the northern Corn Belt.

to 22.7% at Fond du Lac and 27.6% at Watertown. Frequency of daily events remained fairly persistent throughout January and February and increased near the beginning of March at all stations. Autocorrelation coefficients derived from the time series of frequency of precipitation events suggested persistence (significant coefficients) in the frequency of daily events from 1 January to about 1 March. This persistence extended longer into the spring season for western than for eastern stations. For example, the frequency of daily precipitation events was similar from January until at least 26 February for stations east of 94°W longitude and until at least 10 March for stations west of 94°W longitude (Fig. 5). This difference suggests that the transition from winter to spring precipitation patterns occurred 15 days later at western than at eastern stations. We assume that the increase in frequency of precipitation events near the beginning of March corresponds to an influx of warmer and moister air into the northern Corn Belt as a result of a northward shift in the jet stream and a

consequent increase in the number of midlatitude cyclones (Bryson and Lahey 1958; Trewartha 1961). Indeed, Baker and Kuehnast (1978) found precipitation in March to exceed that of preceding winter months by at least 50% in Minnesota because of more frequent intrusions of warm and moist air from the Gulf of Mexico.

Precipitation events of more than 0.25 mm day^{-1} became more frequent with the progression of spring before attaining a maximal frequency of about 35% in late May and June. Thereafter, the frequency of daily precipitation declined through August. A secondary peak in the frequency distribution occurred in September (Fig. 4). This double peak in the frequency of summer precipitation is characteristic of rainfall patterns in the midwestern United States (Keables 1989). Bryson and Lahey (1958) suggest that the increase in precipitation from March into June is a consequence of the shift in the jet stream and development of more midlatitude cyclones. In July and August, the northward migration of subtropical high pressure systems results in develop-

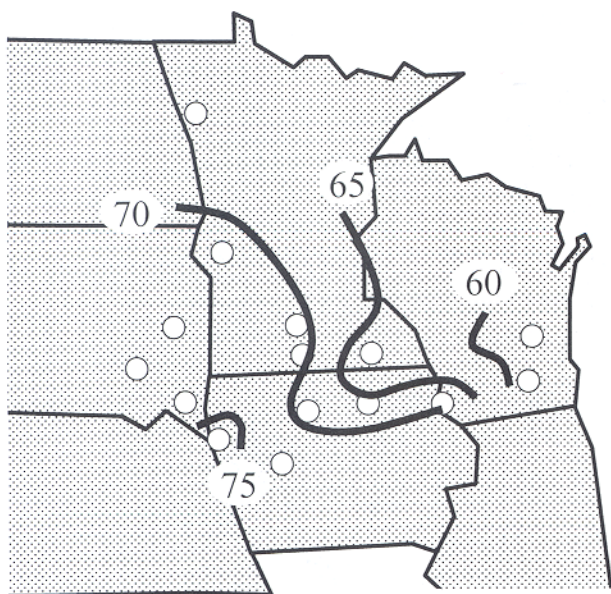


FIG. 5. Isopleths of day of year when persistence in precipitation time series (beginning 1 Jan) fails to exist and signifies a transition from winter to spring across the northern Corn Belt.

ment of more anticyclones and less frequent rains over the midwestern United States. By September, a weakening of these subtropical high pressure systems allows for redevelopment of more midlatitude cyclones and more frequent rains. The June and September maxima in the frequency distribution were also apparent for daily precipitation events exceeding 10 mm (Fig. 4). Thus, the high frequency in all precipitation events occurring in June and September resulted in part from the high frequency in daily events of at least 10 mm. Precipitation events of at least 10 mm in June contributed about 10% to the overall frequency. In addition, the same pattern in the frequency distribution of events of at least 0.25 and 10 mm day⁻¹ suggests that varying amounts of precipitation (10 mm day⁻¹ or less) are related to similar large-scale circulation features.

The maximal frequency in precipitation from late May into June is consistent with Shaw et al. (1960) who found that weekly precipitation was greatest in June in the north-central United States. In our study, the maximal frequency in precipitation at eastern stations occurred during the week of 24–30 May (climatological week 13). This maximum in the frequency distribution was evident at all stations east of 95°W longitude (except Algona, Iowa), including Sioux City, Iowa. Sioux City lies west of 95°W longitude, but exhibited a maximal frequency in late May characteristic of eastern stations. The absolute highest frequency of precipitation for any day of the year across the northern Corn Belt occurred during 24–30 May. Precipitation was recorded in 50% of the years on 26 May at Sioux City, Iowa. Our study also suggests that the maximal frequency in daily precipitation events at western stations occurred

during the 2-week period from 7 to 20 June (climatological weeks 15 and 16). This maximum in the frequency distribution was evident at all stations west of 95°W longitude (except Sioux City, Iowa), including Algona, Iowa. Indeed, the absolute highest frequency of precipitation for any day of the year at Brookings and Centerville, South Dakota, and Crookston and Morris, Minnesota, occurred from 7 to 20 June. The absolute highest frequency of precipitation at these stations ranged from 42% on 12 June at Centerville, South Dakota, to 48% on 17 June at Morris, Minnesota. The frequency of precipitation events declined from late June through July. A local maximum in the frequency distribution then occurred on 2–8 August (climatological week 23). This maximum frequency was evident at all stations except Brookings, South Dakota, and Morris, Minnesota. In the midwestern United States, Trewartha (1961) also found a local maximum in precipitation to occur in early August and associated this increase in precipitation to more frequent development of warm or stationary fronts. Thereafter, the frequency distribution declined to a local minimum between 23 August and 5 September. This minimum precipitation was evident at all stations except Crookston and Morris, Minnesota. Another local maximum in the frequency distribution was also evident from 6 to 19 September (climatological weeks 28 and 29). Precipitation was more frequent from 6 to 19 September than at any other time since late July at all stations except those to the southwest (Centerville and Mitchell, South Dakota, and Carroll and Sioux City, Iowa) and Crookston, Minnesota. At all stations examined in our study, the frequency of precipitation declined from 19 September into early autumn. Trewartha (1961) noted a change in the precipitation patterns occurring about 20 September in the midwestern United States due to an increase in zonal flow that prevents intrusion of warm and moist air from the Gulf of Mexico. The frequency distribution declined to a local minimum during 18–31 October, rose to a local maximum the following week (1–7 November), and descended to another local minimum during 8–14 November. A final local maximum in the frequency distribution occurred from 29 November to 5 December.

Intense precipitation events, in excess of 25 and 102 mm day⁻¹, were uncommon (frequency did not generally exceed 5% and 1%, respectively) throughout the year (Fig. 6). This result is exemplified by the number of daily precipitation events in excess of 76 mm over 100 yr across the northern Corn Belt (Fig. 7). Precipitation events of this magnitude are a potential cause of flash flooding, which threatens the social and economic well-being of communities (Winkler 1988). The number of daily precipitation events in excess of 76 mm over 100 years increased from less than 15 at stations in South Dakota (Brookings, Centerville, and Mitchell) to more than 30 at stations in north-central Iowa (Algona and Carroll). Total events in excess of 76 mm day⁻¹ ranged from 9 at Brookings, South Dakota, to 36 at

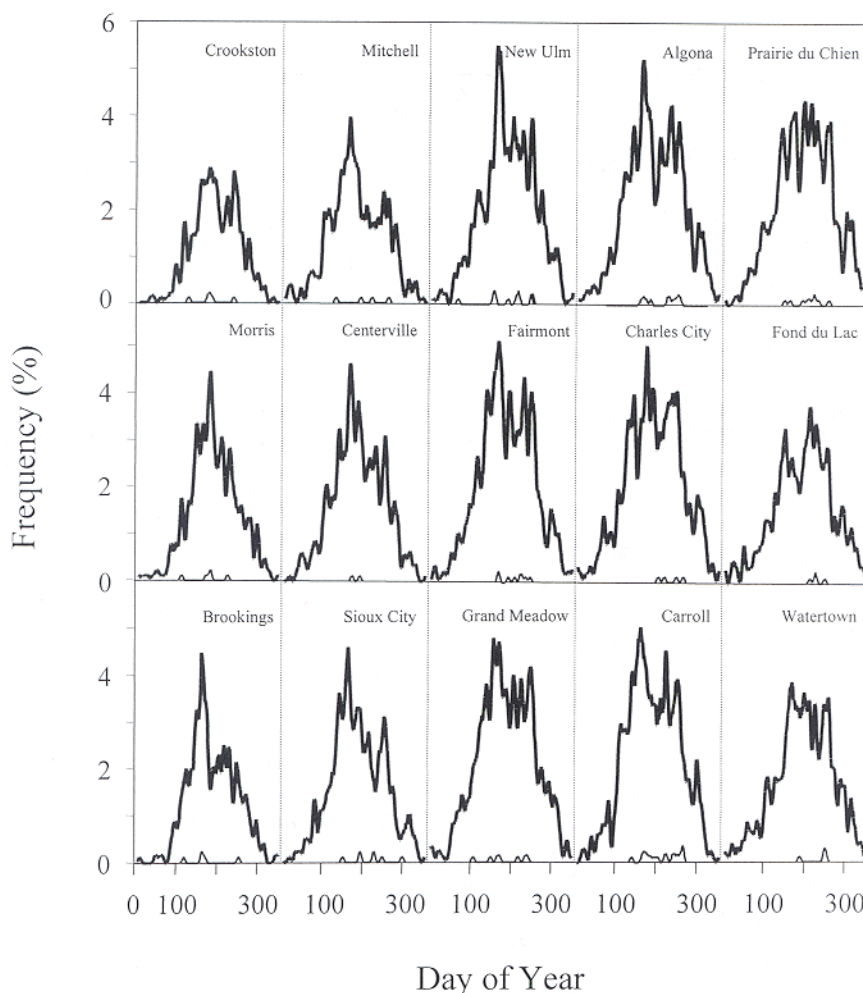


FIG. 6. Frequency distribution (smoothed using a 15-day weighted running average) of daily precipitation that exceeds 25 mm (bold, upper line) and 102 mm during the year at 15 climate stations in the northern Corn Belt.

Algona, Iowa. This spatial tendency for more intense precipitation events at southeastern stations is substantiated by Hershfield (1961) who reported a recurrence interval of extreme storms (more than 76 mm day^{-1}) ranging from at least 2 yr in southeast Minnesota to 5 yr in northwest Minnesota.

The frequency distribution of precipitation events was positively skewed at all except the two most eastern stations in the northern Corn Belt, namely Fond du Lac and Watertown, Wisconsin (Fig. 4). The coefficients of skewness at Fond du Lac and Watertown were not significant ($P = 0.10$), thus indicating normality in the frequency distributions. The coefficient of skewness was significant at all other stations and ranged from 0.23 for New Ulm, Minnesota, to 0.46 for Morris, Minnesota. Thus, the frequency distribution of precipitation events at all except the eastern stations was asymmetric. Precipitation events were more frequent prior to June and then tapered off later in the year. Skewness in the frequency distribution also varied across the northern Corn

Belt, with frequency of daily precipitation events at northwestern stations more skewed than southeastern stations. This variation is exemplified by the skewness in the distribution of precipitation events greater than 10 mm day^{-1} across the northern Corn Belt as illustrated in Fig. 8. The frequency distribution was skewed at all stations, with the coefficient of skewness varying from 0.25 at Watertown, Wisconsin, to 0.93 at Crookston, Minnesota. In addition, the frequency distribution was more skewed for heavy than for light precipitation events at all stations. For example, the coefficient of skewness in the frequency distribution of precipitation events greater than 50 mm day^{-1} ranged from 1.93 at Grand Meadow, Minnesota, to 4.17 at Brookings, South Dakota.

The frequency distribution of precipitation events across the northern Corn Belt exhibited kurtosis. The coefficient of kurtosis in the frequency distribution was significantly ($P = 0.10$) less than 0 at all stations, but only for precipitation events less than 5 mm day^{-1} . Neg-

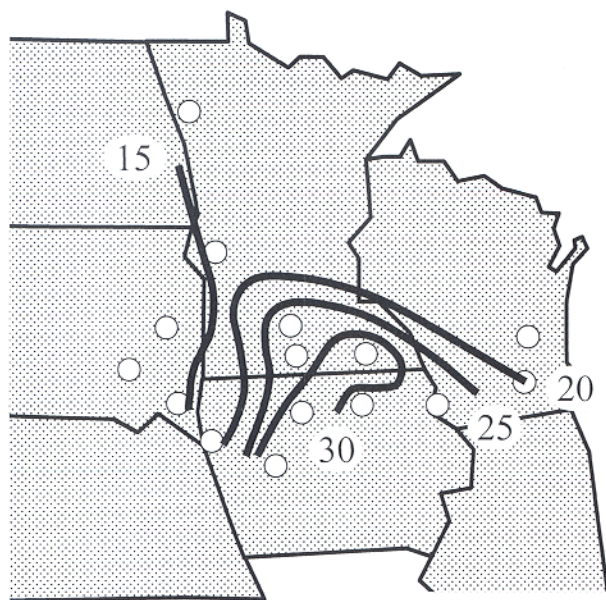


FIG. 7. Isopleths of number of daily precipitation events that exceed 76 mm over a 100-yr period in the northern Corn Belt.

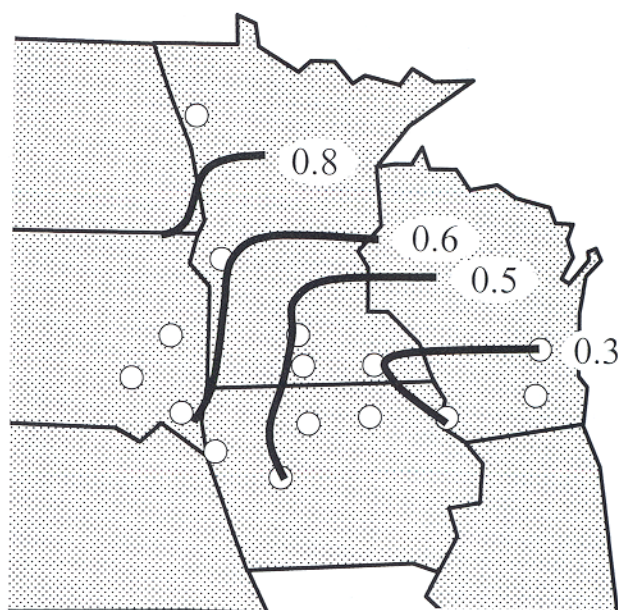


FIG. 8. Isopleths of skewness in the frequency distribution of daily precipitation events that exceed 10 mm in the northern Corn Belt.

ative kurtosis suggests a broad distribution in the number of precipitation events throughout the year. For heavier precipitation events (more than 30 mm day⁻¹), the frequency distribution at all stations exhibited positive kurtosis ($P = 0.10$), signifying a peak in the frequency distribution with more events occurring in summer than winter. Kurtosis varied across the northern Corn Belt and was smaller for southeastern than northwestern stations. This result is exemplified by the spatial variation in kurtosis for precipitation events greater than 10 mm day⁻¹ as illustrated in Fig. 9. Kurtosis varied from 0.5 at Crookston, Minnesota, to -0.8 at Grand Meadow, Minnesota.

Spring versus autumn frequency

The frequency of precipitation prior to crop establishment in spring and after crop harvest in autumn can influence ground water recharge, soil erosion, and leaching or runoff of agricultural chemicals from landscapes. We examined the frequency of events during midspring (15 April–15 May) and midautumn (15 October–15 November), because these dates represent the range when corn is planted (Larson and Hanway 1977; Gupta 1985) and harvested in the northern Corn Belt. Corn is harvested near or several weeks after the last killing frost in the autumn; the median date of the last killing frost (less than -2°C) varied from about 30 September at Crookston, Minnesota, to 30 October at Fond du Lac, Wisconsin.

The mean frequency of daily precipitation events during spring and autumn is illustrated in Fig. 10. In spring, the frequency increased from northwest to southeast across the northern Corn Belt. The frequency of daily

precipitation events of more than 2 mm ranged from 16% at Crookston, Minnesota, to 24% at Watertown, Wisconsin. Similar spatial trends in the frequency of heavier precipitation events were found across the Corn Belt. Trends are illustrated only for 2-mm day⁻¹ events, which are needed to replenish daily evaporative losses in the spring and autumn (Baker et al. 1979). In the autumn, the frequency of precipitation increased from west to east across the northern Corn Belt (Fig. 10). The frequency varied from 8% at Brookings, South Da-

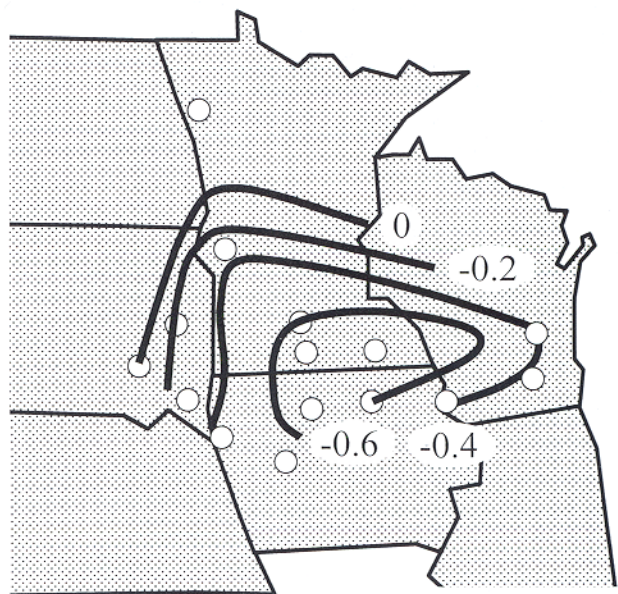


FIG. 9. Isopleths of kurtosis in the frequency distribution of daily precipitation events that exceed 10 mm in the northern Corn Belt.

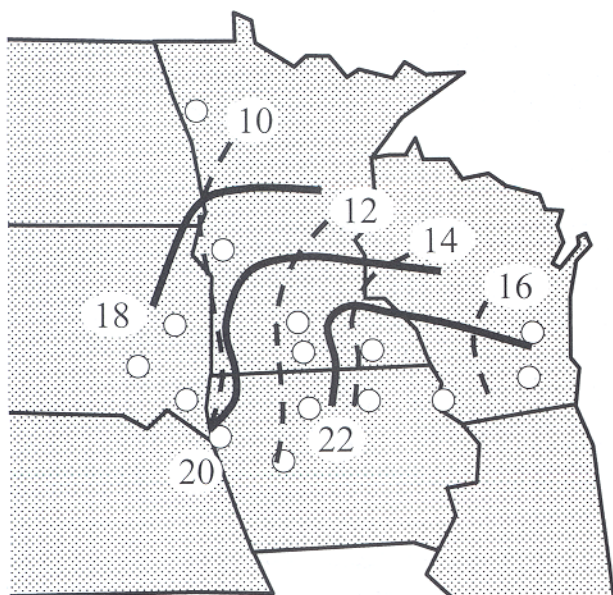


FIG. 10. Isopleths of the mean frequency (%) of precipitation events that exceed 2 mm during spring (15 Apr–15 May, solid line) and autumn (15 Oct–15 Nov, dashed line) in the northern Corn Belt.

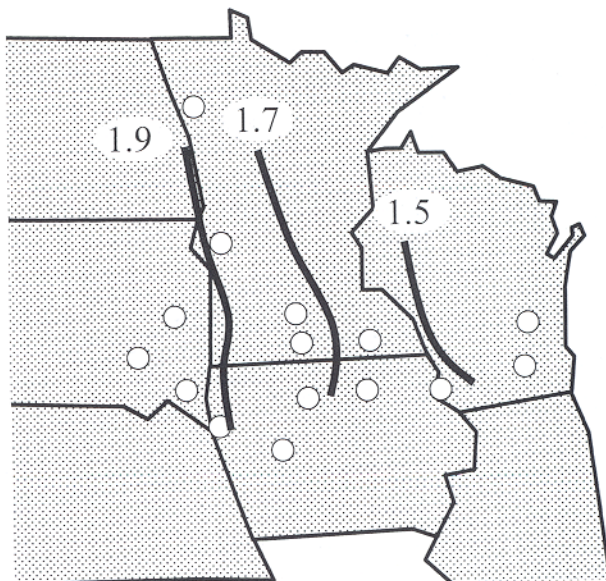


FIG. 11. Isopleths of the ratio between the mean frequency of precipitation events that exceed 2 mm in the spring and autumn in the northern Corn Belt.

kota, to 17% at Fond du Lac, Wisconsin. This longitudinal variation in the frequency of precipitation in autumn is likely due to the preponderance of winds transporting atmospheric moisture from the west in the autumn of the year (Baker and Kuehnast 1978). In the spring, the frequency of precipitation events is affected by intrusions of moisture air from the Gulf of Mexico.

Precipitation was more frequent in the spring than in the autumn across the northern Corn Belt (Fig. 11). Precipitation in the spring was twice as frequent as in the autumn in South Dakota and about 30% more frequent as in the autumn in Wisconsin. Shaw et al. (1960) also reported that weekly precipitation events (from at least 2.5 to 51 mm or more) were more likely to occur in spring than in autumn in the north-central United States. Our findings, however, are contrary to those of Huff and Angel (1992), who reported that extreme precipitation events were more frequent in autumn than in spring. Their study indicates that the most extreme one-day storm of the year is likely to be in autumn and did not consider the distribution of less extreme events.

4. Conclusions

Long-term averages of precipitation are often used in managing water resources, assessing risk in agricultural systems, scheduling field operations, and simulating biological productivity. These averages, however, provide little detail with regard to the daily occurrence of precipitation that is important in assessing the growth response of biological systems to precipitation. Knowledge of the daily occurrence of precipitation will also improve our ability to forecast the weather by compar-

ing the frequency of daily events to those generated by the Medium Range Forecast models of the National Weather Service.

Spatial and temporal variability in the frequency of daily precipitation occurs across the northern Corn Belt. Precipitation occurred more frequently at southeastern than at northwestern climate stations. Precipitation events during the year were most frequent from late May into June and least frequent in winter. Precipitation events were also more likely to occur on days in the spring than in the autumn. The frequency of spring events, however, was 200% greater at western stations and 30% greater at eastern stations in comparison with autumn events. Because spring precipitation events were more frequent than autumn events in the northern Corn Belt, managing soil and chemical resources in the spring is critical for circumventing spring runoff and preserving water and soil quality. In addition, scheduling field operations may be less reliable in spring than in autumn because of more frequent occurrences of precipitation.

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